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Plastic deformation of ice VII at high pressure

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1 Introduction

It is necessary to construct flow laws of high-pressure ices to understand the convecting interiors of large icy moons and planets. Ice VII is stable over large pressure ranges and possibly major constituent of the icy mantle of super-Calisto-size icy planets. Rheology of high-pressure ices has been studied by using a gas-medium deformation apparatus up to several hundreds MPa. To expand the pressure range in the interior of the large icy objects, we conducted a synchrotron radiation study on high-pressure ice rheology

2 Experimental method

Plastic deformation experiments of ice VII were carried out by using a deformation-DIA (D-DIA) apparatus installed at NE7A of Photon Factory, Japan (Shiraishi et al., HPR2011). We used monochromatic X-ray (50 keV, collimated to 100-500 microns) and obtained two-dimensional X-ray diffraction (2D-XRD) patterns every 3-5 minutes using imaging plate (IP). Differential stress of the sample in uniaxial compression can be measured from distortions of Debye ring on IP. X-ray radiography image is used to determine the sample strain during plastic deformation. Changes of grain size can be observed from the number of diffraction spots on 2D-detector.

3 Results and discussion

We first compressed water enclosed in teflon capsule using D-DIA at 300K, and synthesized relatively coarse-grained ice VII. Then, the polycrystalline ice VII was uniaxially deformed at 3-15 GPa, 300-650K (Figure 1), and constant strain rates of around 1.5-6.3 x 10^{-5}/s. The total strain reached up to 34% . The number of diffraction spots increased with plastic strain, which may indicate dynamic recrystallization of ice VII in the dislocation creep regime. Stress-strain curves were measured based on the analysis of the lattice strain recorded on 2D detector (Figure 2). The stress, pressure, and temperature dependence of the strain rate were analysed to construct the flow law of ice VII. The P dependence of the ice VII viscosity is much weaker than that of ice VI (Durham et al., JGR1996), suggesting that the viscosity increase in the deep interior of icy bodies is modest. It has been known that the diffusion mechanism in water ice changes at high pressures from molecular to ionic migration (e.g., Katoh et al., 2002). It has also been suggested that a plastic ice phase may appear when heating ice VII above several GPa (c-p transition shown in Figure 1; e.g., Takii et al., 2008). These changes may affect the ice VII rheology in super-Calisto-size icy planets. Further experiments and quantitative analysis of the obtained creep data are indispensable to know the effects on the plastic deformation of ice VII.

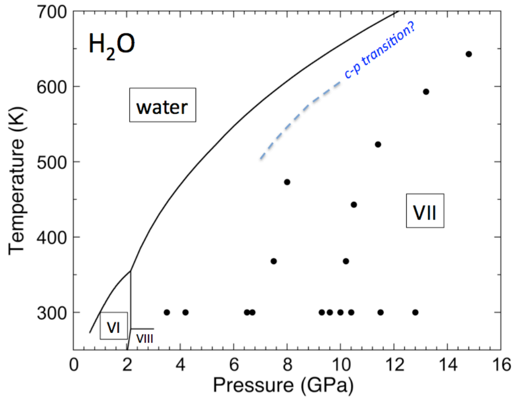

Figure 1 P-T conditions of deformation experiments of ice VII conducted in the present study.

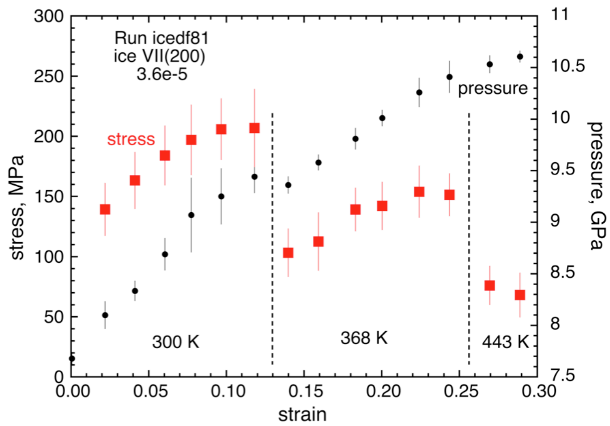

Figure 2 An example of the stress-strain data of ice VII obtained at the strain rate of 3.6e-5 s^{-1} from the synchrotron X-ray deformation experiments at high pressure and temperature.

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